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SCIENCE AND TECHNOLOGY IN BRAZIL: A NEW POLICY FOR A GLOBAL WORLD*

SIMON SCHWARTZMAN

Introduction

THIS IS THE SUMMARY DOCUMENT of the science and technology policy study carried out by the São Paulo School of Business Administration, the Fundação Getúlio Vargas, for the Brazilian Ministry of Science and Technology, within the Program for Scientific and Technological Development (the PADCT II agreement between Brazil and the World Bank). The work was carried out with the co-operation of an independent group of scientists, economists and specialists in science policy in Brazil and abroad, who produced about 40 papers dealing with the international context, Brazil's scientific and technological capacities, the links between science, technology and the economy, and Brazilian institutions for the support of science and technology. The final document was the responsibility of the project's co-ordinating team: Simon Schwartzman, general co-ordination; Eduardo Krieger, biological sciences; Fernando Galembeck, physical sciences and engineering; Eduardo Augusto Guimarães, technology and industry; and Carlos Osmar Bertero, institutional analysis. It does not necessarily express the opinions of the Brazilian government, the World Bank, the Fundação Getúlio Vargas, nor of the individuals who contributed specific studies.

... The paper summarises Brazil's science policy in the recent past, the current situation, and reviews recent transformations of science and technology in an international context. It puts forward some proposals for new directions. To realise these recommendations, the Brazilian government, with the support of the World Bank and other sources, should establish a high-level task force to evaluate this and other policy studies now being conducted, and propose specific policy measures to be carried out by the Ministry of Science and Technology and other agencies, to be presented to parliament for enactment into law when necessary. . .

SCIENCE AND TECHNOLOGY IN BRAZIL

Brazil has developed in the last 25 years the largest system of science and technology in Latin America, one of the most significant among semi-

* An edited and abridged version of the document published by Fundação Getúlio Vargas (Rio de Janeiro, 1994). The specially commissioned papers and the references to other publications are not included here, but are listed in that document.

industrialised countries. There are about 15,000 active scientists and research workers in the country, and about 1,000 graduate programmes in most fields of knowledge. (This figure depends on what a "research worker" is. The Brazilian National Research Council listed 52,863 in 1985, for about 3.5 million persons with higher education degrees. However only 21.7 per cent of these, or 11,000, had doctoral degrees. The number of university professors with doctoral degrees in 1991 was about 17,000, or 12 per cent of the total. This figure is consistent with the number of research proposals presented to the National Research Council and the Foundation for Research Support each year. As for graduate programmes, the figure depends on whether degrees offered or course programmes proper are counted.) Fellowships maintain several thousand students in the best universities in the United States and Europe at any one time. The number of research papers in international publications is the highest in the region.

Research takes place mainly in the major universities, such as the University of São Paulo, the Federal University of Rio de Janeiro, the University of Campinas and the São Paulo School of Medicine; in research institutes linked to the Ministry of Science and Technology, such as the National Institute for Space Research, the National Institute for Research on the Amazon and the National Institute of Technology; in research institutes belonging to the National Research Council (the Brazilian Center for Physics Research, the Center for Mineral Technology, the Institute of Applied and Pure Mathematics, the National Observatory, the National Laboratory for Computer Sciences, the National Laboratory of Astrophysics, the Emílio Goeldi Museum of Natural History, and the National Laboratory of Synchrotron Light); in the Brazilian Corporation for Agricultural Research (EMBRAPA), linked to the Ministry of Agriculture; in the Oswaldo Cruz Institute, linked to the Ministry of Health; in research centres maintained by the largest state-owned corporations, such as Petrobrás (oil), Telebrás (telecommunications), Eletrobrás (electricity) and Embraer (aircraft construction); in research units linked to the armed forces, such as the Air Force Technological Center (CTA); in institutes belonging to state governments, specially in São Paulo, like the Butantan Institute (vaccines), the Biological Institute and the Institute for Technological Research (IPT); and in a few leading private corporations, such as Aracruz Cellose (paper), Itaútec (computers), Aço Villares, Metal Leve (mechanical components), Elebra (computers), and others.

Most research in Brazil takes place in universities. The country has about 1.5 million students enrolled in undergraduate programmes, 30,000 in master's and 10,000 in doctoral programmes. About one third of undergraduate students and most graduate students are in public universities, which are free. The remaining one million attend private institutions, which, with very few exceptions, do not provide graduate education and research. The federal government spent about 3.4 billion dollars on higher education in 1990, and the state of São Paulo an additional 871 million on its three universities. (These figures are only rough estimates, because of high inflation and unstable exchange rates.) The gross per-capita costs for students in public universities are between 5,000 and

8,000 dollars a year, with most of the money spent on salaries and the maintenance of hospitals; it is estimated that hospitals absorb about 10 per cent of universities' budgets—they also have other sources of income. To support their research, university professors have to apply to federal or state agencies, and national and international private foundations; or they have to engage in research contracts with governments, public corporations and, to a lesser degree, private institutions.

TABLE I
Brazilian Expenditure on Science and Technology and Gross Domestic Product, 1980–1990
(Millions of US\$, 1991 ¹)

Year	I Federal Budget ²	II State Budget ²	III Govt. Expendit. Sector	IV Expendit. Prod.	V National Expendit. (III+IV) (% of GDP)	VI National Expendit.	VII GDP ³
1980	824.5	496.8	1,321.3	330.3	1,651.6	0.43	386,863.3
1981	1,519.6	672.4	2,192.0	548.0	2,740.0	0.74	370,279.2
1982	1,863.3	654.6	2,517.9	629.5	3,147.4	0.85	372,122.9
1983	1,475.4	462.6	1,938.0	484.5	2,422.5	0.67	359,727.6
1984	1,426.9	500.7	1,927.6	481.9	2,409.5	0.64	378,422.2
1985	1,953.9	501.9	2,455.8	613.9	3,069.7	0.75	408,151.6
1986	2,288.6	651.3	2,939.9	735.0	3,674.9	0.84	439,451.0
1987	2,556.1	466.9	3,023.0	755.7	3,778.7	0.83	455,424.2
1988	2,506.4	396.7	2,903.1	725.8	3,628.9	0.80	454,918.0
1989	2,147.1	512.5	2,659.6	664.9	3,324.5	0.71	469,663.5
1990	1,679.0	672.2	2,351.2	587.8	2,938.9	0.72	406,906.4

SOURCE: Brisolla, Sandra, *Indicadores Quantitativos de Ciência e tecnologia no Brasil*, Núcleo de Política Científica e Tecnológica, Universidade Estadual de Campinas, São Paulo, 1993. Data from MCT-CNPq/DAD/SUP/COOE.

NOTES: ¹ Deflated according to general price index of the Fundação Getúlio Vargas (IGP-DI/FGV) and converted to US dollars at the average rate for 1991. ² Actual expenditure. ³ Corrected for inflation and converted to US dollars at the average rate for 1991.

The development of these activities was accompanied by the creation of a complex system of institutions, which are at present led by the Ministry of Science and Technology. The ministry is formally responsible for co-ordinating science and technology policy in all areas, directly or through agencies such as the National Council for Scientific and Technological Development (CNPq) and the Financing Agency for Studies and Projects (FINEP). Both the ministry and CNPq also have research institutions under their jurisdiction. The Ministry of Education has a specialised agency to support graduate education in Brazil and abroad, Co-ordination for High-level Manpower Education (CAPES). Most states have secretaries for science and technology, and legislation to provide funds for research, administered in most cases by specialised agencies. The oldest and largest of these, São Paulo's Fundação de Amparo à Pesquisa (Foundation for Research Support—FAPESP), receives about 1 per cent of the state revenues, which in 1992 amounted to about 70 million dollars, and profits from its capital investments. There are ten similar agencies in other states. They are supposed to receive between 180 and 320 million

dollars a year from similar arrangements—including FAPESP—although in practice they receive much less. (It has been estimated that in 1991 the states were supposed to provide 317 million dollars for research, but granted only 84 million. Figures for 1992 were 182 and 82 million. Of the total spent, about 70 per cent came from FAPESP.)

There is a sizeable network of scientific and professional societies publishing around 400 journals, organising conferences and lobbying for their special interests and perspectives. An association of industrial research centres in private companies was created recently. Financial data are not very reliable, since there is no clear definition of what the figures on public expenditure in science and technology really mean. They may refer to administrative and financial expenditure, rather than to science and technology as such, or they may be distorted by variations in inflation. Information about the private sector is scarce. The estimate is that, between 1981 and 1989, Brazil spent between about two and three billion dollars a year on science and technology, amounting to about 0.6 to 0.8 per cent of the gross domestic produce. Of this, only about 6 per cent came from the private sector, and another 10 per cent from state-owned corporations. These resources have been subject to high levels of instability for several years, in a context of near hyperinflation and economic stagnation.

Impressive as some of these achievements may be, they still leave Brazil as a minor participant in the world's scientific community. Articles by Brazilian authors published in the international literature are less than 1 per cent of the total. In 1992, Brazil ranked twentieth among nations in scientific production in absolute terms, behind China, Belgium, Israel and Denmark, and ahead of Poland, Finland, Austria, Norway, Taiwan and Korea. The links of scientific research with the productive sector are weak, and its impact on the quality of undergraduate and technical education is limited, a few significant exceptions notwithstanding.

BACKGROUND

The Beginning: The Development of Science and Technology in a Period of Economic Expansion

Some of Brazil's scientific institutions date from the late nineteenth century, and the National Research Council from the early 1950s. The larger part of the current capacity for science and technology, however, was formed between 1968 and 1980, in a period of military rule. Three factors contributed to this rapid expansion: the concern of some military and civilian authorities with the need to build up the country's competence in science and technology, as part of a broader project of national growth and self-sufficiency; the support this policy received from the scientific community, in spite of earlier (and often continuing) conflicts between scientists and academics and the government; and the economic expansion of the period, in which Brazil's economy grew at an annual rate of 7 to 10 per cent. All contributed to this growth. Another important element was the improvement of the government's ability to

carry out its policies in those years, through the establishment of small, independent agencies outside the federal bureaucracy, and with the help of expanding financial resources.

The policies of the last 25 years should be seen in terms of the changes in Brazilian society and economy in the previous decades. Between 1950 and 1980, Brazil turned from an agrarian into a highly urbanised society, but with high levels of social and economic inequality between regions and social groups. Employment in the primary sector went from 59.9 per cent of the active population to 29.9 per cent in these 30 years, while industrial employment went from 14.2 to 24.4 per cent; the service sector, meanwhile, increased from 25.9 to 45.7 per cent. The industrial sector developed under the protection of tariff and non-tariff barriers that shielded national, multinational and state-owned companies in Brazilian territory from international competition. By 1970, Brazilian industry supplied most of the demand for manufactured goods in the internal market, depending only on the import of sophisticated machine-tools, chemicals, oil and electronics.

A strategic programme for development, set by the military government in 1968, sought to overcome these limitations. The country should build its own basic industry, develop its own sources of energy, and absorb the latest advances in science and technology. Starting with the Second National Development Plan, public corporations were created or expanded, subsidies were provided for the private sector, and barriers were raised against foreign competition, to protect the country's infant industries. Science and technology were perceived as central ingredients in this strategy, and received unprecedented support.

This ambitious project of scientific, technological and industrial self-sufficiency, however, received only scattered support in the private and industrial sector, and remained for the most part restricted to special segments of the state bureaucracy and the academic community. For most firms, including the large, state-owned corporations, the origin of the technology used in their activities was less important than its cost and reliability. Restrictions on the entrance of foreign technology and capital—as happened with the computer sector in the 1980s—were perceived as a hindrance and a burden. This difficulty was accentuated because there was no understanding of the effective mechanisms and policies leading to technological innovation in the productive sector. The need to strengthen the country's basic technological infrastructure—metrology, normalisation, quality control and certification—received only secondary attention, at least until the late 1970s.

Main Initiatives

The main initiatives of this period were the following:

1. The university reform of 1968, with the partial adoption of the American system of graduate education and the reorganisation of the universities in terms of institutes, departments and the credit system.
2. The placement of science and technology under the authorities responsible for economic policy, which allowed for a much higher inflow of resources to science and technology than ever before.

3. The creation of a new federal agency for science and technology under the Ministry of Planning, the Financing Agency for Studies and Projects (FINEP), unencumbered by civil service routines and restrictions, and responsible for the administration of several hundred million dollars a year for the support of science and technology.
4. The establishment of a few large-scale centres for research and development, such as Co-ordination for Graduate Programs in Engineering of the Federal University in Rio de Janeiro (COPPE) and the University of Campinas, focused on technological research and graduate education in engineering and sciences.
5. The setting up of several programmes of military research, such as the space programme and the "parallel" nuclear programme.
6. An agreement with Germany for co-operation on nuclear energy, which was to create an autonomous capability in the construction of nuclear reactors based on locally reprocessed fuel.
7. The establishment of a protected market for the computer industry, telecommunications and microelectronics, linked to an emerging national private sector.
8. The formulation, by the federal government, of successive national plans for scientific and technological development.
9. The establishment of centres for technological research under the main state-owned corporations, which sought to keep abreast with the technological frontier, develop standards and transfer technology to their main suppliers.
10. The strengthening and expansion of EMBRAPA, the Brazilian Corporation of Agricultural Research.
11. The consolidation of peer-review procedures in some of the main public agencies for science, technology and graduate education: CNPq, CAPES and the FAPESP. However, the main federal agency for the development of science and technology in the 1970s and 1980s, FINEP, never introduced systematic peer-review procedures although it works routinely with external consultants. Larger decisions on resource allocation in CNPq also usually remained outside peer review.

The Crisis in the 1980s and 1990s

It is possible to point to several weaknesses in an otherwise successful policy of scientific growth. Links between science and technology and the productive sector remained weak; there was a lack of demand for advanced technology, in an economic environment characterised by protectionism and reliance on cheap labour and natural resources. The only significant exceptions occurred in the modern, export oriented sector of agriculture, which benefited from research on the introduction of new varieties, the control of plagues, and the biological fixation of nitrogen, with very significant gains in productivity; in sectors associated with the large state corporations, such as telecommunications, energy, and the chemical industry; in the production of military equipment; and in the computer industry, in the attempt to link research with a protected industry of small computers for the internal market. In the universities, the new research and graduate programmes often remained isolated from

undergraduate education and teacher-training. The quality of the scientific institutions created and expanded in the 1970s was often not very high, and peer-review procedures for quality control did not always prevail.

After 1980, the science and technology sector entered a period of great instability and uncertainty, characterised by institutional turmoil, bureaucratisation, and budgetary uncertainty. National expenditure on science and technology in the 1980s followed two patterns (see Table I). It grew in the first years of the decade, fell in 1983 and 1984, increased again with the short-lived economic expansion of the Cruzado plan in 1985 and 1986, and fell rapidly when inflation picked up again in 1988, reaching its lowest levels in 1991 and 1992. In 1985, the National Fund for Scientific and Technological Development administered by FINEP retained just one fourth of its value in 1979.

This instability and uncertainty were related to economic stagnation, and also to an expanding number of conflicting interests striving for public funds, and to an increase in political patronage. The science and technology sector became one among many interest groups pressing for more resources, sometimes with partial success, but losing ground in the long run. The same pattern occurred in most public universities, particularly in the federal system. The growing unionisation of academic and administrative personnel allowed for significant gains in salaries, employment benefits, and participation in the management of universities, but stifled those institutions' ability to improve quality and make better use of their resources.

The Program for Scientific and Technological Development (PADCT I, 1985, followed by PADCT II in 1990), supported by the World Bank, was conceived in the early 1980s when the full dimension of the crisis was still to unfold. The programme was supposed to improve the decision-making capacities of government and to strengthen research and development in biotechnology, chemistry and chemical engineering, earth sciences and mineral technology, instrumentation, physical environment and science education. In practice, instead of building upon a basis of existing resources, the programme often became the only source of public support for the fields covered by its priorities. Instead of improving the country's management and decision-making, it may have had the opposite effect, by creating an additional bureaucratic layer upon the existing institutions. Contrary to some claims, the programme did not introduce peer review in Brazil, which had existed since the 1950s. However, it may have strengthened it, since its projects were significantly more substantial and were submitted to more detailed analysis and discussion than those of CNPq.

In the early 1990s, there was a trend towards making science and technology more directly relevant to industrial competitiveness, in a new international context marked by increased market competition and the growing economic importance of science-based industries. This new trend was marked by several features, which included: the gradual extinction of market protection for computers, telecommunications, microelectronics and supplying industries; the transformation of FINEP into an agency dealing almost exclusively with the financing of industrial technology, and

the gradual reduction of the National Fund for Scientific and Technological Development (FNDCT), its main instrument for supporting academic and basic research; increasing support and stimulus for the creation of "technological parks" near the main universities; the freezing, or reduction of large governmental research and development projects, such as the nuclear and the military aircraft programmes; the establishment of a few governmental programmes to stimulate quality and competitiveness in industry; and the increasing concern with university managerial autonomy and accountability, and transparent rules for public financing of the sector.

Given the persistence of economic stagnation and political uncertainty in the early 1990s, this new trend could not become fully established or show its effects. The reduction of FNDCT deprived many research institutions of institutional support and reduced their ability to work properly and to retain the best individuals. The universities suffered from budget limitations, increasing salary costs and the absence of incentives for performance and efficiency. On the positive side, the state universities in São Paulo were granted a fixed percentage of the state's tax basis for their financing, and increased autonomy to manage their resources. In some places, such as the school of engineering at the Federal University of Santa Catarina, the situation led to new co-operation and partnership among university departments, local and foreign governments, private firms and donors, to carry out research and development and for the creation of new high technology firms ("incubators").

THE ACHIEVEMENTS OF THE 1970S AND THE REALITIES OF THE 1990S

The scientific and technological competence acquired by Brazil in the last few decades is an important asset in its continuous drive for social and economic modernisation. There are, however, important questions and concerns about the adequacy of the system of science and technology, as it was organised in the 1970s, to achieve what is expected from it. The difficulty lies partly in the persistence of assumptions that were dominant in the science and technology policies of the 1960s and 1970s, when faced with the realities of the 1990s, and partly in the structures and vested interests created during these years.

The "Endless Frontier"

The basic assumptions that dominated the development of science and technology in Brazil during the 1960s and 1970s were not very different from those in the United States and other developed countries at the time. In both cases there was the notion of science as an "endless frontier", worth expanding for cultural reasons, for its beneficial effects on the quality of education, and for its promise in terms of practical applications. All fields of knowledge were equally deserving, and all good projects and initiatives should get public support. There were other resemblances: the importance given to military research and development; the notion that scientists should be supported financially by the state, but be free to control their institutions and distribute research

resources according to their own criteria; and the assumption that social and economic benefits to society as a whole would necessarily derive from basic science and technology in the universities and military research in government institutions.

Planning

There were also important differences. Brazilians believed more than Americans did in comprehensive planning, and in planning for science and technology. There was, however, as there still is in Brazil, a dire need for reliable information, and stable decision-making procedures for the allocation of resources and the establishment of long-term projects. The tradition was to try to fulfil these needs with comprehensive planning exercises, which could be turned into law and administered by the bureaucracy, thus making further decisions unnecessary. Three national plans for scientific and technological development were issued from the early 1970s. Complex co-ordinating bodies—such as the Council of Science and Technology, CCT—were devised to link the research of different ministries. The Ministry of Science and Technology was created in 1985 in response to demands from leading figures in the scientific community, who expected it to fill this planning and co-ordinating role, and thereby make it more relevant to the country's economic and social needs. The notion that these links could be achieved through centralised planning contributed to the development of large bureaucracies to administer science and technology. CNPq and FINEP increased their staffs several times between the 1960s and the 1980s, and the bureaucratic apparatus of the new ministry also grew.

Import Substitution in Science

Another difference was that the development of science and technology in Brazil was understood as part of a broader pattern of import substitution which was dominant in the economy, and which led to barriers against foreign competition and the protection of infant industries. Although Brazil never attempted to develop a "national science", and valued its access to the scientific international community, the level and intensity of international interchanges was never as intense as that of other small scientific communities; its research institutions and programmes were seldom exposed directly to international standards of quality and evaluation. Considerations about regional inequalities and short-term needs, and political pressures for the creation of academic and research institutions throughout the country, often led to weakened criteria in the allocation of resources by the government agencies.

Elitism in Technology and Education

A final feature of the development of Brazilian science and technology has been the elitism of its policies for technology and education, despite the political and socially radical outlook of many of its promoters. Military technology was expected to be the harbinger of economic and technological modernisation, and this led to a disproportionate concern in

government, diplomatic and academic circles, with international constraints on the transfer of sensitive technologies. The two PADCT programmes placed strong emphasis on the most advanced technology, with a much smaller place given to science education, management and diffusion. Except in the field of health, there were no organised efforts to bring the benefits of scientific knowledge to the population as a whole, or to the basis of the productive system. In spite of the initial influence of the American land-grant colleges, Brazilian agricultural education and research remained restricted to a few institutions, and oriented to the capital-intensive, export sector of the economy. The recent effort to develop an indigenous skilled personnel and institutions in computer science concentrated on the protection of the national hardware industry, rather than on the generalisation of the use of the new technology and competence throughout society.

In education, Brazil tried to generalise the university research model before making any serious attempt to deal with the problems of basic, secondary, technical and mass higher education. In consequence, the country has, simultaneously, some of the best universities and graduate programmes, and one of the worst and most unequal systems of basic education in the region (Table II). In practice, the model has remained restricted to a few public universities in São Paulo and in the federal system. Most other public institutions have incorporated the institutional features and costs of modern universities (including full-time teaching, departmental organisation, integrated campuses, and free tuition), without adequate mechanisms for ensuring quality and the efficient use of public resources. About 65 per cent of students in higher education have no access to public institutions, and attend the less good private institutions.

TABLE II
Education in Brazil: Population of 5 Years of Age and Above
(percentage)

	Brazil	Women	Rural	Northeast
<i>Literacy (1990): Can read and write (self-reported)</i>				
5 years and more	76	77	58	57
10 to 14 years	86	89	70	67
60 years and more	56	53	32	44
<i>Educational attainment (years completed)</i>				
Total (%)	100	100	100	100
one or more	82	82	65	65
two or more	77	77	57	57
three or more	68	70	46	48
four or more	59	60	34	39
five or more	41	42	17	28
six or more	33	34	11	22
seven or more	29	30	09	19
eight or more	25	26	07	16
nine or more	18	19	04	12
twelve or more	06	06	01	03
Total (thousands)	113,629	58,373	28,011	31,614

SOURCE: Fundação IBGE, *Anuário Estatístico*, 1992.

Brazil has always been a highly stratified and unequal society. Even when the intention was there, governments faced enormous difficulties in reaching the broader population with services like education, health and extension work. The situation should be reversed, but this does not mean that efforts to create good universities and competent research groups should be postponed until the problems of basic, technical and secondary education are solved, since these skills are essential for carrying on the needed transformations. It would be a mistake, however, to suppose that investment in scientific, technological and educational could not have a broader impact on professional education and the dissemination of general and technical competence than they have in fact had. They can, but specific policies are needed for this.

NEW REALITIES

Changes in the Role of Science and Technology on the International Scene

The international background has changed dramatically since Brazil began its drive to develop science and technology in the 1960s. The main features of the new situation can be described as follows:

1. Science and technology are much closer to industry and markets than before. Industries depend, for the development of new management skills, processes and products, on specialised knowledge that cannot be generated any more, as a matter of course, in their daily activities. The consequences have been an increase in investment in research and development, the setting up of specialised laboratories and research departments, and a search for new links with universities. There is renewed concern with the problems of intellectual property, which occur in association with an expanded knowledge industry, carried on through licensing, technical assistance projects and international consulting.
2. The pace of technical innovation and competition in industry has accelerated, requiring from firms a permanent capacity to change their organisation, absorb new technology and processes, and generate new products. This is leading to significant changes in the composition of the industrial labour force, with more emphasis on highly skilled and motivated workers at all levels, and drastic reductions in administrative personnel and unskilled employees. The consequences of this acceleration in pace of technical progress and the intensification of market competition include the growing internationalisation of industries and markets and the re-definition of production lines, with specialisation in some segments of the production chain or market. New associations and mergers, very often with companies from other countries, are also prompted by the high costs of research and development and the shortened life-cycle of new products.
3. Science is becoming more global. The speed, quality and low cost of the flow of international information bring both research workers and research sites into immediate contact. The spreading of technological products and processes by international firms disseminates similar patterns of consumption, organisation and work. It is much easier now to

have access to the international scientific community than in the past, and the international mobility of talented scientists has become simpler. Simultaneously, there are increasing requirements for entry into the international scientific community in terms of the standardisation of scientific instruments, language and patterns of communication, leading to new inequalities and concentrations of resources and skills.

4. As the economic and military importance of scientific and technological knowledge increases, there is a growing tendency to limit its diffusion through legislation regarding intellectual property and through governmental barriers to the diffusion of "sensitive" technology. This tendency, however, is offset by the intense international competition of firms and governments to sell their technological products, and by the lack of well-defined boundaries between academic—and therefore free—and proprietary knowledge. The net result is that the bulk of modern technology is available for countries with the necessary competence in engineering and basic sciences, except for a few military items that can still be controlled by the major powers.

5. More recently, the end of the cold war has forced the major powers into a difficult process of reducing their military establishments, which is altering the traditional association between military research and development, industrial technology and basic academic research. Part of these resources might move to applied fields like health, the environment and energy, and new associations between government, research institutions and private corporations are likely to emerge. In these countries, scientific innovation in the civilian sector will probably be driven by markets and short-term social demands, rather than by government "requirements". It will be more closely related to manufacturing and service, and more cost-conscious than in previous years.

Changes in the Nature of Scientific Enterprise

The "simple linear model" of scientific development and technological change is being abandoned. It assumed the existence of a pattern of fundamental research yielding discoveries and leading to the application of experimental discoveries in applied science. This allowed for acts of invention, which provided the basis of entrepreneurial innovation, creating new products and processes, which were later diffused by imitation and "reverse engineering". The current view is much more complex. Scientific discoveries often take place in the context of application; there is no longer such a clear-cut distinction between basic and applied work; tacit knowledge and incremental improvements have increased in relative importance compared with isolated scientific breakthroughs. One consequence of this changing perspective is that support for basic research has lost ground, when it is not linked to identifiable products and results.

The development of new patterns of international scientific co-operation has led to the establishment of large-scale international ventures such as the Human Genome Project and research activities in the fields of meteorology, global warming, astrophysics, and regional co-operative projects. While traditional "big science" programmes, such as the European Council for Nuclear Research (CERN), were characterised by large

scientific installations, recent ones tend to be organised in terms of extended and closely linked networks of scientists and research groups. For small scientific communities, the alternatives are either to participate in some aspects of these ventures, or to lag further behind.

Because of increasing costs, economic benefits and potential dangers, scientific and technological activities are more closely watched by society than in the past. Public controversies blur the frontiers between technical expertise and common knowledge, and a host of new activities and disciplines linked to scientific assessment have emerged, dealing with questions like technological forecasting, technology assessment and the evaluation of environmental effects of innovation. The social sciences have acquired new relevance in this context, in the study of the economics of science and technology, the understanding of the social processes of education and the production of knowledge, the interpretation of public controversies, and in the analysis of public policy-making related to the field of science and technology.

The traditional organisation of the scientific enterprise is under criticism. The division of academic departments and scientific institutions along disciplinary lines is being questioned regarding its ability to provide the proper training and conditions for interdisciplinary research. At the same time, there are no clear alternatives to the conventional organisation of teaching and education along disciplinary lines, introducing a further source of tension between teaching and research. Government agencies for the support of science are being revised and transformed. The links between universities, government and industry are being deeply changed by new patterns of technical education, co-operative research and financing, which generate new opportunities and tensions. Traditional scientific careers are perceived as less rewarding, respected and secure than in the past, while new professional patterns emerge.

Changes in the Nature and Capacities of the Brazilian State

Brazil, which presented one of the world's highest rates of economic growth until the 1970s, did not adapt to the changing international environment of the 1980s, and entered a prolonged period of economic stagnation cum inflation from which it has still to recover. Different explanations are given for this, from the exhaustion of the import substitution model that had characterised the country's economy since the 1930s, to the political and institutional inability of governments, since the 1980s, to carry out long-term policies, in a context of international hardship and intense political competition for public subsidies. There is a clear notion, today, that the state has to reduce its size and its presence in the economy, while gaining competence to set and carry out long-term policies of economic growth, social welfare and environmental protection. It is not clear, however, how this change should affect science and technology.

This situation of instability and lack of vision has affected science and technology in two important ways. The most obvious has been the reduction of financial resources for most existing programmes, and the lack of perspectives for new projects and initiatives, even when inter-

national commitments, such as the loan contracts with the World Bank and the Interamerican Development Bank, required well-defined matching funds according to prescribed time-tables. Probably more important have been the problems of institutional and financial instability. The Ministry of Science and Technology changed its name and status several times, budgets allocated to research and development institutions oscillated, and the actual delivery of these funds depended on constant, painful and daily negotiations with often unsympathetic economic authorities in the lower ranks of the bureaucracy. Not only were resources limited, but there was no consensus in government, public opinion or international agencies, about the importance and role of scientific research, or about matters like the relative emphasis to be placed on basic and applied, civilian and military, or academic and industrial research. This instability has been a matter of great concern, given the long time it takes for scientific institutions to mature, compared with the speed at which they decay in conditions of budgetary and institutional insecurity.

In the early 1990s, the state of Brazilian science and technology can be summarised thus:

1. The federal agencies for the support of science and technology—FINEP and CNPq—have very limited ability to grant resources for research projects. Most of CNPq's resources are used for fellowships, while FINEP specialises in loans to technology projects in the private sector. On the other hand, FAPESP has been preserved as an efficient and respected institution, and has even increased its share of the state's main tax revenue, from 0.5 to 1.0 per cent, supposedly for applied work and industrial development. Several other state-level institutions for the support of research institutions were created in the late 1980s, but few are active and efficient.
2. The administrations of some federal agencies for science and technology suffer the effects of swollen bureaucracies, low salaries and the political militancy of their employees. Others, on the contrary, are understaffed, and unable to appoint adequately qualified persons. CNPq has been particularly affected by a permanent tension between its employees and the council's academic advisory bodies. Most federal research institutions, including the research institutes under CNPq, are paralysed by lack of resources and incentives.
3. There is no consensus about what to do with the large-scale projects of the past, which are in large part paralysed by lack of resources. The military doctrine of technological development from the 1970s seems intact within the armed forces, in spite of the current constraints. None of the large projects has been discontinued—the atomic submarine, the space project (including the development of rockets and satellites) and the construction of military aircraft. The space project is moving from military to civilian control, and the government has sent a bill to Congress to create a Brazilian space agency, which would consolidate this transition.
4. Benevolent legislation allows for the early retirement—at the age of about 50, with full benefits—of many professors in public universities and the civil service. About 30 per cent of current expenditure in the federal universities is used for retirement benefits, and the figure is growing. It is

difficult to know how this affects the pool of active research workers, whether they are continuing their activities in other (and sometimes the same) institutions, and how they are being replaced. The general perception is that the private benefits of early retirement, combined with the instability and low prestige of many teaching and research institutions, are depleting Brazil's active scientific community. As long as this does not change, it is important to encourage retired, well-qualified professors to remain productive in other roles, for instance, in new careers as entrepreneurs. Retirement should be used also as an opportunity to appoint a new generation of young academics and research workers.

5. Within these extremely adverse conditions, the Ministry of Science and Technology is trying to put forward some new ideas and policies for science and technology. One of its main tasks has been to ensure a regular flow of budgetary and non-budgetary resources to the sector. The proposal for the federal budget is to obtain between 1 and 1.5 billion dollars for the activities under the Ministry of Science and Technology for 1994. The government has decided that a substantial part of the resources obtained through the privatisation of public companies should go into science and technology, and recent legislation has granted tax benefits to firms engaged in technological development. The official expectation is that these two sources alone could double the resources for science and technology in 1994.

The ministry is also engaged in continuous negotiations with economic authorities to stabilise the flow of resources to the agencies, and with international institutions for continuing or renewed support for the sector. The ministry's second goal is to continue and conclude some of the large projects that have started but are blocked by lack of resources. The two most important are the space and satellite programme and the Laboratory of Synchrotron Light. The ministry has also proposed a bill establishing a unified career structure for scientists and employees in federal institutions. In the Ministry of Education, CAPES, the agency for high-level manpower education and training, maintains a stable line of fellowships and support for graduate programmes. Some projects created during the Collor period (1990-92) to stimulate quality and competitiveness in industry are still in place, although with very few resources.

A NEW POLICY WITH A WORLD-WIDE PERSPECTIVE

In spite of the large gap in science and technology between Brazil and the leading industrial societies, there may be an opportunity for convergence that should not be missed: access to international information is cheap; circulation and mobility of scientists are intense; technology for products and processes is offered in a highly competitive international market; multinational corporations spread their branches and research facilities throughout the world, depending on local conditions. The main conditions necessary to seize this opportunity and share these resources in knowledge are a country's own social capacities, which are essentially a matter of education and scientific competence. With science and technology becoming more international, the requirements to participate in their benefits remain local and national, and depend on purposeful efforts by local and national governments.

There is a definite need to move from the previous mode of scientific and technological development into a new one, better suited to current and future realities. Science and technology are more important than ever for Brazil, if the country is to raise its standard of living, consolidate a modern economy, and participate as a significant partner in an increasingly integrated and interconnected world. The Brazilian economy must modernise, and adjust to an internationally competitive environment. This requires that education should be expanded and improved at all levels. As the economy grows and new technology is introduced, new challenges will emerge in the production and use of energy, environmental control, public health, the management of large urban conglomerates, and changes will occur in the composition of the labour force. Strong indigenous competence is necessary to participate as an equal in international negotiations with important political and economic consequences for Brazil, in areas such as the protection of intellectual property and rights of access to information, norms of environmental control and the establishment of technical standards in international communication networks.

Laissez-faire in scientific and technological development will not produce the necessary competence on the scale and quality needed for these tasks, or make them as useful as they could be. There is little place for protected technology under artificial conditions, and large-scale, sophisticated and highly concentrated technological projects are unlikely to benefit education and industrial development as a whole. Attempts to bring the whole field of science and technology under the aegis of centralised planning and co-ordination run the risk of stimulating large and inefficient bureaucracies, and of stifling initiative and creativity.

The new policy should undertake apparently contradictory tasks: stimulating the freedom, initiative and creativity of scientists, while establishing strong links between their work and the requirements of the economy, the educational system and of society as a whole; and making Brazilian science and technology truly international, while strengthening the country's educational system and its science and technology. To achieve this, individual scientists, and their research units or laboratories, should be freed from bureaucratic and administrative constraints, and stimulated to look for the best opportunities and alternatives, in the country and abroad, for the use and improvement of their competence. This requires, in turn, a competitive environment—based on public incentives and private opportunities—that rewards achievement, increases the costs of complacency and underachievement, and directs a substantial part of the resources for research and development towards a few important and strategic goals. More specifically, the new policy should undertake the following tasks:

1. To increase the links between academic science and the productive sector, and to increase the latter's share in the national effort to develop science and technology, by approaching the patterns of the modern, industrialised economies, where most work on research and development takes place in the productive sector. This requires significantly increased private investment in research and development, not a reduction of the already limited public funds.

2. To create two different "markets," one for academic science, another for applied technology. The academic market needs a system of rewards and incentives for scientists, appropriate careers, and the means to increase public support for science. The market for applied technology should combine the requirements of competence and quality with those of economic feasibility and social needs.
3. To increase the links between science, technology and education, from graduate programmes down to technical and basic education.
4. To invest heavily in the development of the capacity for innovation of the productive system as a whole, through incentives, extension programmes and the strengthening of the infrastructure for basic technology.
5. To support a few integrated projects of clearly identified social and economic relevance which need research and education in science and technology, in areas such as energy, environmental preservation and control, transport, public health, food production, and in social fields such as basic education, poverty, employment and the management of urban conglomerates.
6. To create the conditions for Brazil's participation in international programmes dealing with world-wide issues.
7. To make governmental agencies for science and technology more flexible and bound to peer-review procedures, and to stimulate research groups and institutions to seek out partnerships and support from a variety of sources and through different procedures, beyond what governments can provide.

POLICY RECOMMENDATIONS

To achieve these goals, the following recommendations are made:

A. To redirect the country's technology policies, in line with the new economic realities

Technology policies are needed to enable the country to enter a new pattern of industrial growth, centred on increasing levels of competitiveness. In the short run, policies should aim at the reorganisation and technological modernisation of the industrial sector. Then, permanent policies should induce the more dynamic sectors of the productive system to enter a continuous process of innovation and the incorporation of new technology, to follow the rhythm of technical progress in the world economy. Both approaches require the incorporation of existing technology into the productive process. Sectoral policies are needed for the reorganisation and technological modernisation of the less efficient parts of the economy, and for the consolidation and expansion of the more dynamic industrial sectors. Support for research and development should be selective, and clearly associated with broader processes of innovation based on the transfer, diffusion and absorption of technological competence.

The issue of protectionism versus market competitiveness in scientific and technological development should be dealt with in pragmatic, rather than ideological terms. It is impossible, and it would be tragic, to shield

the country from the technological revolution that is taking place in the world. A crucial element of this revolution is the role of multinational corporations and international trade in the development and diffusion of modern technology, which makes the issues of technological development and international trade so intertwined. At the same time, a country should not renounce its instruments of technological and industrial policy, including tax incentives, tariff protection, patent legislation, government procurement and long-term investments in technological projects, in association with the private sector. The aim of these policies should be always to improve the country's scientific and technological competence, and reap the benefits of increased efficiency, productivity and trade. In this context, adequate legislation for patents and intellectual property should be established, with the understanding that they are necessary for the normalisation of Brazil's relations with the industrialised countries, although, in itself, such legislation could neither guarantee nor jeopardise the technological advancement of Brazilian industry.

B. To protect the existing pool of scientific competence

Many of the best institutions and groups in research and development are being dismantled as a result of an absolute lack of resources. Emergency measures are needed to counteract this process. The government should guarantee a stable and predictable flow of resources to its main agencies in science and technology for their daily routines and "over the counter", peer-reviewed research. The problem is not just of limited resources, but above all of lack of institutional stability and commitment within the sector, since the level of resources needed is not very high. Special programmes like the PADCT could be used for this purpose.

Not only do agencies require resources, but the most qualified research institutions and groups should be given the means to preserve their best research workers and their projects. A proposal has been discussed for several years to establish a network of laboratories and research groups to be supported by government through long-term grants based on past performance ("laboratórios associados"); this requires prompt implementation. Estimates of the size and cost of such a network vary, but the scale of the operation is not very difficult to determine. Of the estimated 15,000 active scientists in the country, about a third, or 5,000, could be included in 200 such "laboratories" of 25 persons each, supported with 1 million dollars a year on average, or 40,000 dollars per person, 200 million dollars in total. This would be the cost of maintaining the pool of scientific competence, providing a basis from which other policies can be devised. A similar amount will be needed to provide these laboratories with basic equipment and infrastructure. Most of this is already being spent as salaries by universities and other government agencies, so the cost of this programme would be even less (although the resources for research and infrastructure should be provided in addition to what is needed for regular graduate education). Ideally, the programme should compensate for oscillations in salaries, guarantee resources for current expenditures, and provide means for the acquisition and modernisation of scientific equipment, regardless of a group's institutional location.

Resources should be allocated competitively, under strict peer review, and for limited periods, typically three to five years. The criteria for allocation should be the laboratories' achievements, the quality of their scientific staff, their ability to obtain funds from other sources, and their long-term perspectives and projects.

This network of research laboratories should be strengthened by a line of support for individual scientists, allowing them to move around to find the best places to use their competence; laboratories could be rewarded for the quality of persons they attract.

A competent and respected peer-review procedure is essential for the project of "laboratórios associados" to work. In the long run, difficult problems of choice between equally competent groups and proposals may appear, so decisions will require procedures that go beyond traditional peer review. However, given the currently small size of Brazil's scientific community, most competent groups are likely to be supported, without increasing the levels of expenditure excessively.

C. To develop a three-pronged policy for the development of science and technology, with clearly distinguished support mechanisms for basic science, applied work and extension and education

The fact that basic science, applied research and development and high-level technical education are very often indistinguishable, and take place simultaneously in the same institutions, does not mean that they should not be treated separately in terms of their supporting mechanisms, working from different perspectives and with different approaches.

Basic Science Research and Education

Basic or academic science, broadly understood as research work that does not aim to satisfy short-term practical demands, remains necessary not only for its eventual role as the source of opportunities for application, but as an indispensable public good. Scientists should be trained on a broad fundamental basis, so that they do not become obsolete in a short time. This purpose is not in contradiction with applied work, but should not be jeopardised by over-emphasis on efforts to help solve the short-term operational problems of the productive sector. In spite of the growing presence of proprietary knowledge in modern societies, academic science is also expanding, and the resources it can expect from the private sector are not very high. The information generated by basic science is free for the private sector—although it is paid for by society as a whole—and it is the main source for the acquisition and spreading of the basis of tacit knowledge that permeates the whole field of science, technology and education. For a leading country, heavy investment in basic science may be problematical, since the results can be appropriated by other countries and regions at very little cost. For the same reason, investment in basic science in small scientific communities can be extremely productive, since it allows the tapping of the international pool of knowledge, competence and information. This is the rationale for projects such as the National Laboratory of Synchrotron Light, now under construction by CNPq.

Besides its eventual effects in the productive sector, basic science can play a fundamental role in enhancing the quality of higher education for engineers and for society as a whole. However, this does not take place as a matter of course. Universities have to develop clear links between their graduate and undergraduate programmes; intellectual and financial investments have to be made in the development of materials for science teaching, from handbooks to educational software and experimental kits. When these links and investments exist, basic science becomes more legitimate, and is more likely to be supported by society.

Changes are also necessary in scientific and graduate education. Master's degree programmes should be shortened, and turned either into well-organised courses of professional specialisation, or short entrance programmes leading to doctoral degrees. Non-degree, specialist courses should be stimulated, with minimal bureaucratic formality, and as self-supporting as possible.

"Globalisation" requires a profound rethinking of the old dilemma between scientific self-sufficiency and internationalisation. The experience of small, high-level scientific communities in countries like Canada, Israel, the Netherlands and the Scandinavian countries, shows that this may be a spurious question. These countries increase their competence through a purposeful effort to be present on the international scientific scene, by the extensive use of the English language, participation in joint research projects, evaluation of their research by scientists from other countries, and a constant international flow of students, research workers and information. They are not less developed, and their science is not less relevant for their societies, for that reason.

The current fellowship programmes of CAPES and CNPq for studies abroad need to be revised. Fellowships should be awarded only to first-rate students going to first-rate institutions, and with a clear expectation of returning to productive work in Brazil. Fellowships for doctoral degrees should be combined with "sandwich" fellowships for doctoral students in Brazilian institutions, and short-term support for training in laboratories and companies abroad. Procedures should be devised to constrain the beneficiaries to pay back the money received if they fail to get their degrees or to return to their institutions; fellowships to countries and institutions with poor records of academic achievement for fellows should be avoided. Under these conditions, the current number of fellowships awarded should be maintained and even expanded. The existence of good quality doctoral programmes in a given field does not preclude the need to send a permanent flow of students to the best foreign universities. Provisions should exist for postdoctoral programmes both abroad and in Brazil, and to bring highly qualified scholars from other countries for extended periods, or even on permanent appointment, to Brazilian university and research institutions.

Applied Science

The central feature of applied science is that it has a user, and applied knowledge tends to be proprietary. The main clients for applied science in Brazil have been the military, the large state-owned corporations and a

small section of the private sector, including the export-oriented agricultural firms.

Applied research and development should be evaluated in terms of its scientific quality and its medium or long-term practical results. When the client is a public institution, such as the military or a state-owned corporation, research and development tends to be secretive, large and long-term. Evaluation is very difficult to carry out, since research results are not open to publication, scrutiny by peer review, or market competition. Lacking appropriate procedures for evaluation, applied research and development in the public sector risks being expensive and of doubtful quality; the same holds for publicly subsidised research and development in private firms.

However, there is a clear trend away from these kinds of activities in research and development . . . Most public corporations are either being privatised or forced to rely on market mechanisms to survive. In both cases, publicly subsidised applied research and development will tend to diminish. The Brazilian experience of subsidised research and development in the private sector is not very good. If loans are granted below market interest rates, there may be many takers, but outcomes are often poor. There is a room, though, for special procedures to finance long-term and joint projects in research and development that would not otherwise find support through commercial banks. General policies and support mechanisms for applied research and development are difficult to devise, since they refer to an extremely variegated range of activities, and require different combinations of economic, scientific and strategic considerations. A few suggestions can, however, be made:

1. Research groups in universities and governmental institutes should be strongly stimulated to forge links with the productive system and to engage in applied work, while maintaining a high level of activity in academic and basic research. It is as unwarranted to expect all basic scientists to be linked to production as to assume that they should be kept isolated from each other. There is no reason to believe that applied work would necessarily distract scientists from their basic and academic oriented activities. However, tensions and conflicts of interest may arise, and need to be administered case by case. Links between academic research and the productive system can be made at multiple levels, depending on the capacities and needs of each side. They can go from help in the solution of short-term problems and difficulties faced by industries, to the transfer and scaling up of innovations produced by research centres for industrial production; and, at the higher end, to the development of large-scale, co-operative projects of research and development. Links can be established either with single institutions or with associations and consortia of users, as in the example of the Institute of Forestry Research of the University of São Paulo. Resources for applied work should not come from the budget for basic activities, but from particular sources in governmental agencies, special programmes, private firms and independent foundations.

2. Governmental agencies dealing with matters requiring research work, as in health, education, environment, energy, communications and transport, should have resources to contract for research with universities and

research institutions on matters of interest. This practice should prevail over the tendency of agencies to create their own research institutions, and their projects should be subject to joint evaluations by peer review and policy oriented authorities. Research institutes and centres in public agencies and state companies should be placed under the oversight of peers, and required to compete for research support outside their agencies.

3. Current military projects should come under technical, academic and strategic evaluation with the participation of selected, highly qualified scientific advisers, and be either streamlined, discontinued, reduced or converted to civilian projects.

4. Research programmes in applied fields like electronics, new materials and biochemistry, should only be established in association with identified partners in industry, who should contribute with their own resources, and be involved from the beginning in the establishment of appropriate objectives. They should be subject to independent evaluations of economic, managerial and scientific feasibility, and monitored on those terms.

5. New participants should be brought into projects of local and regional development, including local and state governments, business associations, financial institutions, universities and technical schools.

Education

The main challenge for Brazilian science and technology in the coming years is to spread aptitude for innovation horizontally to the productive system as a whole, and to raise the educational level of the population. Until this is done, the scientific and technological establishment is bound to relate only to a small part of the country and its economy, with limited resources and relevance.

Policies for science and technology should not wait for educational reform, but they cannot be expected to succeed without profound transformations in the educational system as a whole, through increased access to educational opportunities, improvement in the quality of basic and secondary education, strengthening of technical education and diversification, and better use of public resources in higher education. Questions of educational policy lie beyond the scope of this document. However, a few items should be stressed regarding the relations between the sectors of education and science and technology:

Technical education: Brazil has maintained a wide gulf between education for the academic professions, including engineering, and middle-level professional training; the first is provided by universities, the second by federal and state technical schools (and also by industry and commerce through their own institutions, SENAI and SENAC). The knowledge-intensive basis of modern industry and services requires the development of general skills by the technician, and proximity with industry for the institutions trying to provide technical education through formal courses. Brazil has lagged behind in the world-wide trend towards post-secondary, short-term course programmes as alternatives to conventional university

education. The expansion of post-secondary, technical education, developed with close links to industry, should become a central task for public universities and state governments. Although more difficult at the beginning, this new emphasis could prove more useful than the sheer expansion of evening course programmes that have become mandatory for public universities in the recent past—and more realistic, in budgetary terms, than the proposed multiplication of federal technical schools operated by the Ministry of Education.

Extension work and continuous education: University research departments and institutes should be stimulated to become more intensely involved with extension work and continuous education. An important activity in this regard is the systematic translation into Portuguese, or the rewriting of science education textbooks and engineering documents—handbooks, standards, technical manuals for craft and skilled workers—needed for general use in industry and education. These activities already take place in some universities, but are usually considered of low prestige, and inimical to academic excellence. This does not have to be so. High quality centres of research can attract more resources, increase their relevance and involve more persons through extension activities. Institutions with little to offer in terms of research can gather strength and recognition, and provide their students with significant opportunities for practical training. Since most of these activities can be paid for by users, they do not require many additional resources, and there should be the means to provide rewards, incentives and recognition for this type of work.

Teaching of science and technology: Academic departments in universities should take more responsibility for undergraduate education. The current departmental structure tends to leave undergraduate programmes without intellectual leadership, while teaching undergraduates is often seen as a burden by professors engaged in graduate education and research. Incentives should be created to stimulate scientists engaged in research to get involved with undergraduate education, by writing textbooks, bringing undergraduates to their research projects, and participating in the upgrading of their courses. Fellowships for undergraduates ("bolsas de iniciação científica") should be expanded, and successful involvement in undergraduate education should be added as a criterion for CAPES in its evaluation of graduate programmes.

General education: Most undergraduate education in Brazil, as elsewhere, is in fields like administration, languages, social sciences and the humanities. These can be considered "general education" course programmes, since they entail little specific knowledge, and are supposed to provide the students with a broad spectrum of cultural, social and historical disciplines. There is a tendency to see these "soft" fields as a waste of time and resources, with the assumption that they are not directly relevant to the production of goods. However, general intellectual skills, and social and cultural awareness are central components of modern economies and societies, which are characterised by intense flows of information and communication, a continuous expansion of services and a

shifting social and economic environment. This neglect should be reversed, with the graduate and research sector taking responsibility for improving the quality of secondary and undergraduate general education, through direct involvement in the production of good quality textbooks, the development of curricula and new teaching methods. Here again, adequate procedures should be devised to make these activities more rewarding and better appreciated.

Distance learning: Modern technology for distance learning has not been adopted in Brazil except in some isolated instances in basic education. A systematic effort should be made to utilise international experience, and a few universities should be encouraged to begin pilot projects using the newly available instruments, from computers to electronic mail.

D. Infrastructure for the dissemination of information and knowledge

New and systematic procedures to incorporate high technology into the industrial process should be developed, with strong emphasis on the development and dissemination of norms and standards, information, and procedures for technological transfer and quality improvement. Brazil has several institutions created for these tasks, such as the National Institute of Metrology, the National Institute of Intellectual Property and the Brazilian Institute for Scientific and Technological Information (IBICT). These institutions, however, have lived in a no man's land between scientists in academic institutions and the productive sector, both of which were either protected from external competition, or linked directly to their own sources of information and technology outside the country. Without closer interaction with the users of their services, these institutions have tended to become rigid and bureaucratic, weakening still further their links with the scientific and productive sectors.

To reduce this problem, users should play a much stronger role in the definition of the goals and practices of these institutions. A well-organised and properly financed system for the storage and diffusion of knowledge is necessary to ensure easy access for scientists to libraries and data collections in Brazil and abroad. Significant advances have occurred in the last few years, through the gradual generalisation of access to the Internet and similar networks for Brazilian universities and research groups, and the development of computerised library catalogues in some of the major universities. Now it is necessary to make these links more widely used, more effective and more transparent to the individual research worker, and to establish means of bringing the documents and data to the scientists' places of work. A coherent policy for creating, maintaining and expanding these information resources is needed, which should rely on the competence developed by FAPESP, the National Laboratory of Computer Science Research (LNCC), the Institute of Applied and Pure Mathematics (IMPA), and other groups that have built and developed the current facilities.

E. Institutional reform

For these policies to be carried out, governmental agencies for science and technology policy should become smaller, more flexible and efficient.

Brazilian agencies for science and technology are considered more efficient, and with fewer problems of political patronage and bureaucratic formalism, than most of the Brazilian civil service. However, with a few exceptions, the general evaluation of the main governmental agencies is not very positive. CNPq has grown to be a large bureaucracy, going from 1,502 employees in 1988 to 2,527 in 1992, about half of them without a university degree (Table III). Its administrative expenditure has varied enormously throughout the years, and most of its resources are now given to fellowships. Research workers and fellows applying for its resources complain constantly about difficulties in getting information and receiving their fellowships and grants on time. The agency has never established a competent information system about its own activities, and there is little or no follow-up of the results of its investments in research and graduate education.

FINEP also increased its bureaucracy to about 700 employees, while its resources shrank. There are no established dates for submission of projects and proposals nor public announcement of awards. Without systematic peer review, there is no information on how decisions are made. In both cases, problems have been compounded by budgetary uncertainties. The agencies do not know how much money they will have at any given time, and their decisions are often based on expectations that are not fulfilled. Finally, these agencies have not established adequate procedures to receive proposals in constant values and protect their grants from inflation. In consequence, when a project is finally approved, its value is significantly lower than when it was presented, and still lower when the money is received and spent.

TABLE III

CNPq's Budget According to Main Lines of Activity, 1980-1992
(Millions of US\$, 1992 ¹)

Year	Fellowships	Grants ²	Institutes	Administra- tion	Other ³	Total
1980	42,252.3	23,166.3	26,233.9	40,598.9	4,243.2	136,494.6
1981	46,567.7	21,815.5	29,557.7	41,837.5	2,420.1	142,198.5
1982	72,396.3	37,793.5	34,489.4	35,032.4	2,265.8	181,977.4
1983	68,137.6	28,106.6	26,949.6	28,769.8	3,194.6	155,158.2
1984	61,400.8	21,521.1	23,092.8	37,682.4	5,034.5	148,731.6
1985	88,153.1	41,517.0	33,141.5	33,631.7	5,212.8	201,656.1
1986	94,630.1	50,996.2	35,497.9	27,931.3	7,552.3	216,607.8
1987	184,069.4	48,886.4	57,739.4	63,729.7	4,416.3	358,841.2
1988	238,004.4	46,552.1	49,322.2	47,281.9	4,415.3	385,575.9
1989	236,143.1	33,570.1	85,569.2	48,693.0	22,732.4	426,707.8
1990	178,339.5	41,672.8	50,529.1	36,513.3	14,684.5	321,739.2
1991	232,440.4	19,884.0	30,838.3	26,361.2	14,907.9	324,431.8
1992	193,820.4	7,635.8	30,655.5	17,362.2	10,603.2	260,077.1

NOTES: ¹Compensated for inflation according to the General Price Index of Fundação Getúlio Vargas, and converted to dollars according to mean exchange rates of 1992.

²Includes special projects. ³Includes debt service payments, "fringe benefits" to employees, persons working for other governmental agencies.

SOURCE: CNPq, *Informe Estatístico*, Brasília, IV (April 1993), p. 13.

In contrast, FAPESP, in the state of São Paulo, and CAPES, at the Ministry of Education, are perceived as successes. FAPESP works almost exclusively through peer review, its administration is very small, communication with applicants is very efficient, its grants are fully corrected for inflation, and it has well-designed follow-up procedures for its grants and fellowships. CAPES suffers some of the difficulties of being within the Ministry of Education, but has an established tradition of peer-review assessments. Its leaders have been always recruited among persons of good academic standing, and its bureaucracy remains small.

These experiences provide a basis for the following suggestions for institutional reform:

1. The Ministry of Science and Technology should restrict its role to matters of policy, financing, assessment and evaluation, without carrying on research and development under its direct administration. Although a science adviser or an equivalent cabinet-level position for science and technology is clearly necessary, the necessity of a formal ministry of science and technology, with all its overhead costs and exposure to political patronage, should be reconsidered.
2. The existing system of federal institutions for scientific and technological support should be evaluated in terms of its ability to perform the functions needed by the sector: support for basic research, support for applied projects, large and small research grants, fellowship and training programmes, scientific information, norms and standards, and others. Brazil needs a federal agency to provide long-term, sizeable grants for institutions and co-operative projects. This was the role played in the past by the National Fund for Scientific and Technological Development (FNDCT), administered by FINEP. Whether these resources should be managed by FINEP, CNPq or by a new institution should be examined as part of a broad review of the roles, jurisdiction and competence of the existing agencies.
3. Financing agencies should be organised as independent, state-owned corporations, and free of formal and bureaucratic constraints. They should be under strict limitations regarding the percentage of their resources they can spend on administration, and should be supervised by high-level councils with the participation of scientists, educators, entrepreneurs and government officers. They should rely on external advice for their decisions, and their bureaucracy should be limited to the minimum.
4. Research institutions and public universities should not be run as sections of the civil service. They need to have the flexibility to set priorities, seek resources from different public and private agencies, and establish their own personnel policies. If this is not changed, there is the alternative of developing hybrid institutions with flexible mechanisms coexisting with more rigid procedures (the Brazilian academic community has some experience in this). Universities should develop appropriate settings for interdisciplinary work in new fields such as biotechnology and artificial intelligence.
5. No research institution receiving public support, and no government programme providing grants, fellowships, institutional support or other resources to the science and technology sector, should be exempt from

clear and well-defined procedures of peer evaluation, combined, where necessary, with other types of economic and strategic assessments. Peer-review procedures should be strengthened by the federal government, freed from pressures of regional, professional and institutional interest groups, and be given strong international connections. For instance, research proposals could be easily distributed to international referees through electronic mail.

6. It should be the task of the Ministry of Science and Technology to stimulate such reforms in other branches of the federal government. The Ministry of Education should have a particularly important role in maintaining the quality and the autonomy of the research groups in the federal universities.

7. It should be also the task of the Ministry of Science and Technology, with the Ministries of Finance and Foreign Affairs, to keep the channels open for international co-operation between Brazil, international agencies and institutions, and the international scientific community. The World Bank, the International Development Bank and the United Nations Development Programme have played important roles in providing resources for capital investment, the support of research and the institutional development of Brazilian institutions. This presence should be maintained not only because of the resources provided, but because of what they bring in terms of international perspectives and standards. In future, such agencies could be very helpful in a process of institutional reform. As a rule, co-operation among scientists, research institutions and private foundations in different countries is established directly: they need the support, but not the interference, of governmental agencies.

F. Goal-oriented projects

The broad changes suggested in this document do not preclude the adoption of well-identified projects linking science, technology and the productive sector, aimed at the strengthening of specific fields and orientations in the natural and social sciences, the establishment of instruments for the diffusion of science and technology and education, and others. Proposals of this kind are present in the background studies commissioned for this study, and will emerge as a matter of course whenever decisions have to be made about the allocation of scarce resources, the beginning of new lines of work, and the phasing out of others. It is necessary to develop a list of main areas of established competence and social relevance to be the focus of future investment; to identify areas that should be phased out, or reduced; and areas of special weakness and competence in need of strengthening and support. Two very broad principles should underlie this policy-making process:

1. It is inappropriate to assume that science and technology will develop and increase its usefulness in a peripheral region if left alone to respond to market mechanisms of economic and scientific competition. The distribution of science and technology, as is well known, is very unbalanced in any given field and region, and the current expansion of communications and trade is leading to further concentrations of knowledge, competence and technical resources. Policies are needed for

general and technical education, for bringing flexibility and accountability into publicly supported institutions of higher education, research and development, and for introducing standards of quality. The trend towards concentration cannot be stopped by policies of isolation and self-sufficiency, or subsidies to second-class institutions and research groups. But it is not a "zero-sum situation". As the world becomes more integrated, information circulates, and knowledge bases increase, and new opportunities arise to be grasped. For this to happen, opportunities have to be properly perceived and understood, and adequate investments in education should exist.

2. Brazil has had some experience of integrated programmes covering specific areas of interest, such as tropical diseases, natural resources, energy and computer sciences. PADCT has followed a similar pattern, by choosing a few selected areas for support, and assigning a given fraction of its resources to them. An integrated programme would have, ideally, resources for combined activities of basic and applied research, graduate education and training. For the fields chosen for such programmes, the benefits seem obvious, since their resources are guaranteed, and the links between basic and applied research and education can be made more coherent.

There are, however, three pitfalls for such programmes, which should be avoided. First, they run the risk of isolation. As with any applied project, integrated programmes need to have clearly identified and active partners outside the research and education sector—be they the health ministry, the electronics industry or public utility companies. In fields that are economically relevant, they should be linked to specific industrial policies, and the participation of relevant business leaders. When this pattern is not present, the results of the integrated project are not used, and the effort may be wasted. Second, there is always the temptation to distribute the resources for research and development arbitrarily among programmes, creating unwarranted imbalances. Third, self-contained programmes are prone to shun peer-review evaluations and give excessive protection to a few institutions and research groups, disregarding excellence in favour of selected subjects or problems. If these difficulties are considered—if there are clearly identifiable partners in government and industry, if there are no arbitrary "block assignments" of resources, and if peer-review procedures are kept in place—integrated programmes can be important instruments for improving the country's capacity in science and technology.

CONCLUSION

The plurality and complexity of modern science and technology require the research institutions in universities, government and even the private sector to engage in a plurality of activities, from basic to applied science, from graduate education to extension work and teacher-training. They should also be stimulated to diversify their sources of funds, from government to private companies, non-profit foundations and paying clients and students. Specialisation will take place, is necessary, and should grow through a combination of external incentives and internal

drive. Scientific research and development, to remain alive, should take place in a highly internationalised and competitive environment for resources, prestige and recognition. And the leading scientists should be also entrepreneurs of this enterprise for the promotion of the growth of knowledge.